Sensor Problems

Conceptual

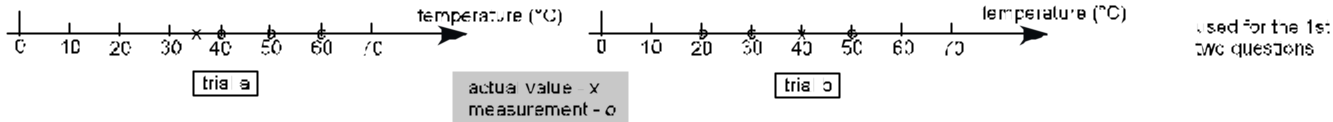

Figure P8.1

1. Trial **b** displays greater systematic error than trial **a**.
2. Trial **b** displays a greater range of random error than trial **a**.

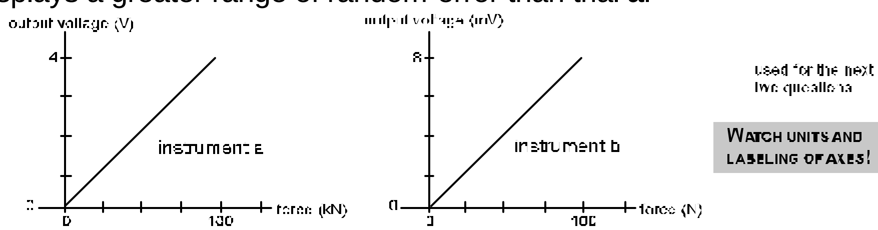

Figure P8.2

3. Instrument **a** is more sensitive than instrument **b**.
   Why or why not? ____
   ____
4. Instrument **b** has greater range than instrument **a**.
5. A linear force transducer has an output of 20 mV when measuring 100 N and has an output of 100 mV when measuring 300 N. What is the zero offset in mV? That is, what is the output voltage for zero input force?
6. A linear displacement transducer reads 0 mm when measuring 0 mm and reads 110 mm when measuring 100 mm. What is the actual displacement when the transducer reads 385 mm?
7. (***T/F***) Resistance is a function of a resistor's dimensions and its conductivity. That is, resistance is a function of geometry and material properties.
8. (***T/F***) A photoconductor's principle of operation is that exposure to photons changes its dimensions and thus changes its resistance.
9. (***T/F***) Given two photoconductors, identical in all respects exept that one has a greater recombination time, the one with the greater recombination time will display the greatest change in conductivity due to optically generated carriers.
10. (***T/F***) A metallic strain gage (120 Ω nominal resistance) with a strain gage factor of 2 and which is subjected to a tensile strain of 0.01 would have an approximate resistance of 122.4 Ω.
11. (***T/F***) A metallic strain gage (350 Ω nominal resistance) with a strain gage factor of 2 and which is subjected to a compressive strain of 0.005 would have an approximate resistance of 346. 5 Ω.
12. Show how metallic strain gages could be used to measure torque. Your solution should include an explaination of the physical principles and a diagram showing the meaurement

system and its dimensions. The solution should also include a calculation of the nominal resistance (resistance when the torque is zero) and how the resistance would vary with torque.

13. Show how metallic strain gages could be used to measure force. Your solution should include an explaination of the physical principles and a diagram showing the meaurement system and its dimensions. The solution should also include a calculation of the nominal resistance (resistance when the force is zero) and how the resistance would vary with force.

14. Show how metallic strain gages could be used to measure pressure. Your solution should include an explaination of the physical principles and a diagram showing the meaurement system and its dimensions. The solution should also include a calculation of the nominal resistance (resistance when the pressure is zero) and how the resistance would vary with pressure.

15. (***T/F***) The physical principle of operation of a thermocouple is that a voltage, a Seebeck voltage, results when two dissimilar metals are connected and that this voltage is a function of temperature.

16. (***T/F***) Themocouples are fragile and must be handled with extreme care.

17. (***T/F***) Thermocouples have a limited operating temperatures and typically are used between the freezing and boiling points of water.

18. Show how a capacitance sensor could be used to measure displacement. Your solution should include an explaination of the physical principles and a diagram showing the meaurement system and its dimensions. The solution should also include a calculation of the nominal capacitance (capacitance when the displacement is zero) and how the capacitance would vary with displacement.

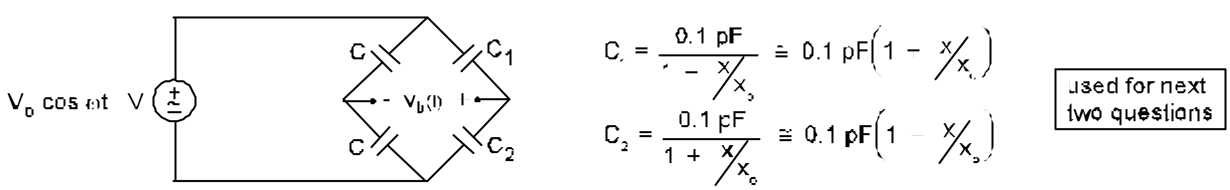

Figure P8.3

19. (***T/F***) For x>0, and $v_b(t)$ expressed as $V_b\cos \omega t$, $V_b>0$.

20. (***T/F***) The magnitude of the current from the the source increases as ω increases.

21. Show how a capacitance sensor could be used to measure pressure. Your solution should include an explaination of the physical principles and a diagram showing the meaurement system and its dimensions. The solution should also include a calculation of the nominal capacitance (capacitance when the pressure is zero) and how the capacitance would vary with pressure.

22. Show how a capacitance sensor could be used to measure acceleration. Your solution should include an explaination of the physical principles and a diagram showing the meaurement system and its dimensions. The solution should also include a calculation of the nominal capacitance (capacitance when the acceleration is zero) and how the capacitance would vary with accleration.

23. (***T/F***) Capacitive humidity sensors have time constants on the order of a few milliseconds.

24. Briefly explain the physical principles of capacitive humidity sensors.

25. Discuss the physical principles that explain self inductance.

26. Explain the physical principles of mutual inductance.

27. (***T/F***) Inductor one, L_1 = 1H. Inductor two, L_2, is identical to L_1 except that L_2 has twice the number of turns as L_1. This implies that L_2 = 0.25 H.

Why or why not? ____

____

28. (***T/F***) Two inductors, L_1 and L_2, are identical apart from L_1 having a core twice as long as L_2. This implies $L_1 = 2L_2$.

29. (***T/F***) Given two inductors, L_1 and L_2, with 1 A into each. The inductor with the larger inductance must have the higher magnetic flux, ϕ, in its core.

Why or why not? ____

____

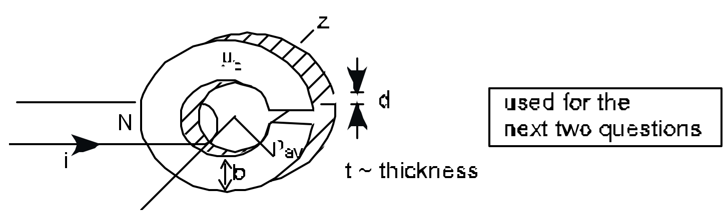

Figure P8.4

30. (***T/F***) All other factors constant, as d increases, the inductance of the coil will increase.

31. (***T/F***) All other factors constant, if ρ_{av}, b, and t were all doubled, the inductance would remain unchanged.

Why or why not? ____

____

32. Explain how the Hall effect can be used to determine whether a semiconductor material is n-type or p-type.

33. (***T/F***) When using the Hall effect to measure a magnetic field, the Hall voltage increases linearly with the magnetic field.

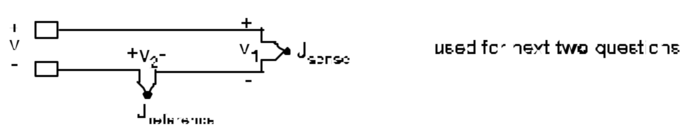

Figure P8.5

34. (***T/F***) Suppose $J_{reference}$<0°C.   The voltage v in the diagram above will indicate a higher temperature at the sensing junction than is actually there.

Why or why not? ____

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35. (***T/F***) If the temperature of J_{sense} becomes lower than that of the $J_{reference}$, v will be negative.

36. (***T/F***) The output voltages of thermocouples are typically between one and five volts.

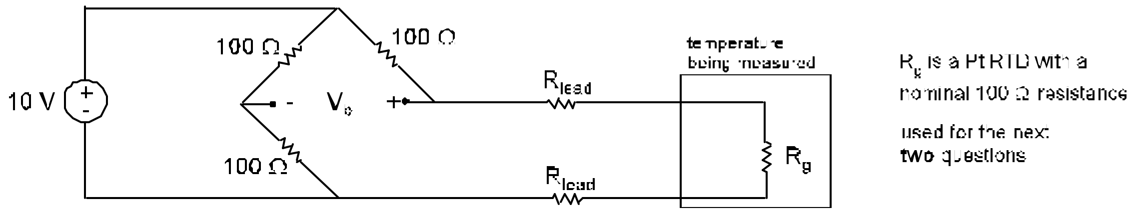


Figure P8.6

A 100 Ω nominal RTD (that is, R_{RTD} = 100 Ω @ 0°C) is used to measure temperature. Note that the resistance of the metal RTD (here Pt) increases as temperature increases.

37. (***T/F***) A two-wire measurement is used in determining an RTD temperature. For T>0°C, V_b>0.
Why or why not? ____
____

38. (***T/F***) The presence of lead resistance will tend to cause V_b to indicate too high a temperature.

39. Discuss the physical principles behind the Fabry-Perot interferometer.

40. What scale of displacements could be resolved with a Fabry-Perot interferometer using red light (assume λ = 670 nm)?

41. Would the resolution of the Fabry-Perot interferometer be increased or decreased if one used blue light, λ = 440 nm, rather than red light, λ = 670 nm?

Workout Problems

1. Derive an expression for V_b in the four-arm active bridge shown below. R_1, R_2, R_3, and R_4 are all strain gages with resistances R±ΔR, where ΔR = SeR. Assume in the derivation that ΔR<<R.

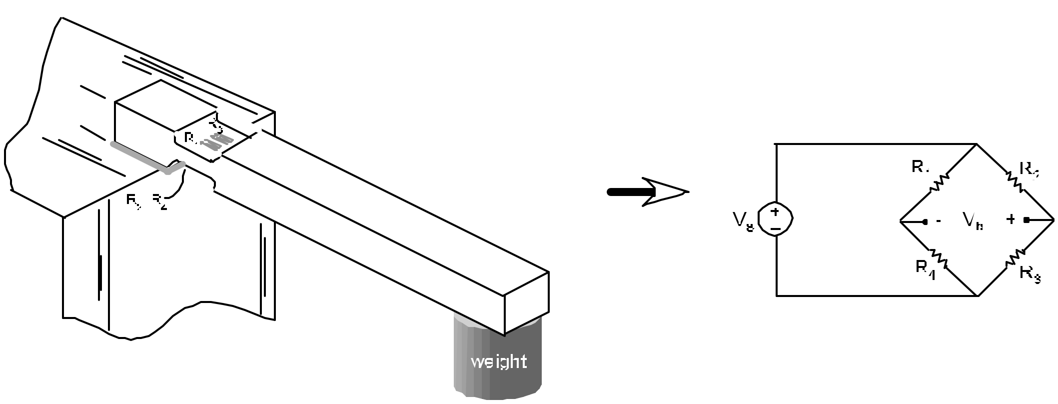


Figure P8.7

2. When a given load is placed on a four-active arm cantilever load cell shown above, ε=0.0002.

   S=2, V_s=15V, R_1, R_2, R_3, and R_4 are 350Ω strain gages. Use R_a = 1 kΩ

   i) What is V_b in Fig.?

   ii) Specify the amplifier below to give an output of V_0=60 mV for these conditions.

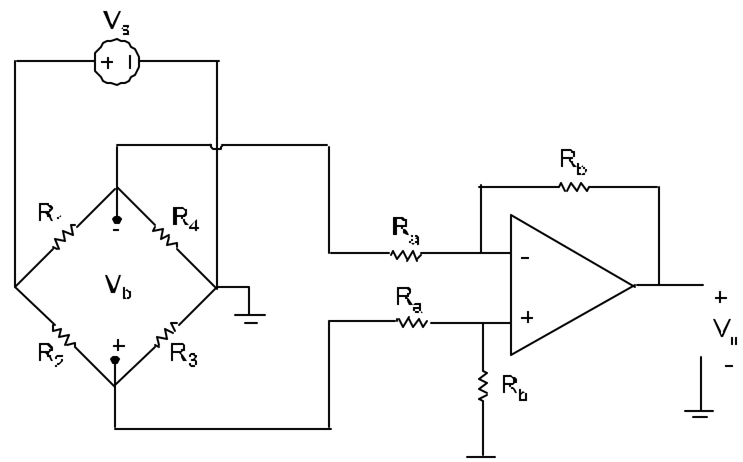
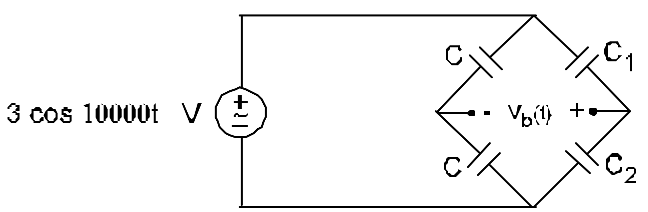


Figure P8.8

3. Derive an expresssion for $v_b(t)$. Assume $x<<x_0$.



$$C_1 = \frac{0.1\text{ pF}}{1 - x/x_o} \cong 0.1\text{ pF}\left(1 + x/x_o\right)$$

$$C_2 = \frac{0.1\text{ pF}}{1 + x/x_o} \cong 0.1\text{ pF}\left(1 - x/x_o\right)$$

Figure P8.9

4. Referring to Fig. P8.7 above, and given that C_1 and C_2 are derived from a MEMS accelerometer like that described in Example 8.3 with a natural frequency of 15,000 r/s, determine $v_b(t)$ for an acceleration of 50 g.

5. Given the LVDT shown below, derive

$$v_o = \begin{cases} \dfrac{|M_1 - M_2|}{\sqrt{R_p^2 + (wL_p)^2}} \sin\left[wt - \tan^{-1}\left(\dfrac{wL_p}{R_p}\right)\right] & \text{for } M_1>M_2 \\ -\dfrac{|M_1 - M_2|}{\sqrt{R_p^2 + (wL_p)^2}} \sin\left[wt - \tan^{-1}\left(\dfrac{wL_p}{R_p}\right)\right] & \text{for } M_1<M_2 \end{cases}$$

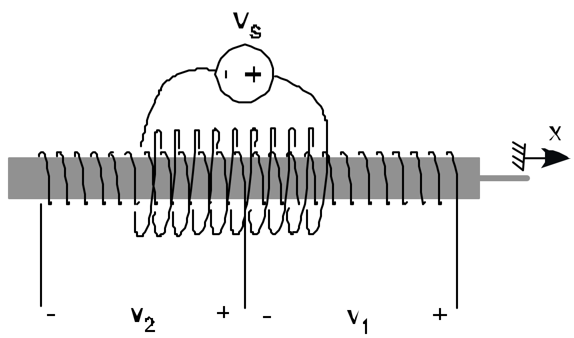


Figure P8.10

Assume the current drawn from the LVDT is negligible so that the voltage drops across $L_s/2$ and $R_s/2$ can be neglected and the back EMF into the primary circuit from the secondary current can also be neglected

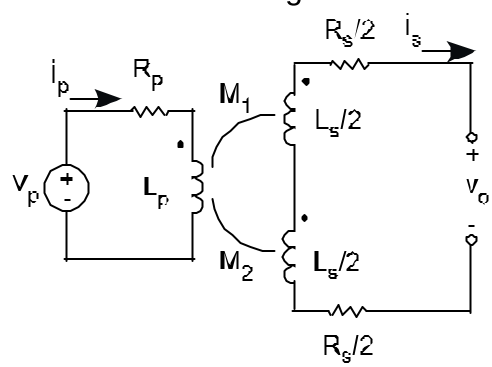


Figure P8.11

6. i) Explain the operation of the DC output LVDT shown below.

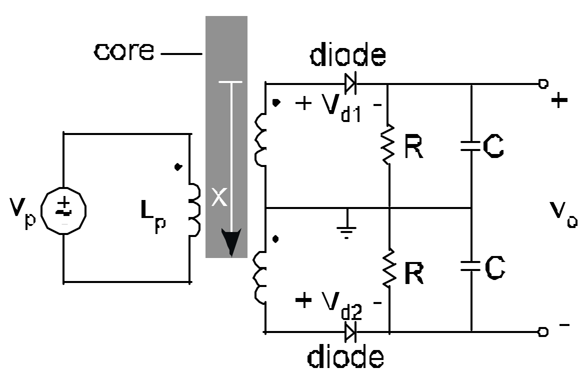


Figure P8.12

ii) Given an excitation frequency (V_p) of 1000 Hz, choose R and C so that the ripple is less than 10% of the peak voltage of $v_o(t)$. Choose R = 10 kΩ.

7. Show that the outgoing beam is zero except in the region of $x = n\frac{l}{2}$, where $n \in J$.

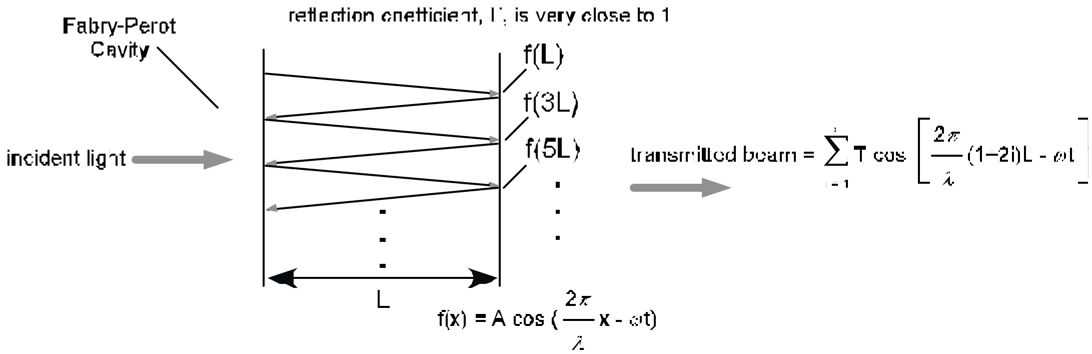


Figure P8.13

8. Use Simulink® to simulate the step response of the non-linear RC circuit shown below for $0 < t < 400\ \mu s$. $R = 50\ k\Omega$ and $C = 0.002\ (1 – 0.02\ V_o)\ \mu F$. *Note:* Since the input is a step function, the initial voltage at $t = 0$ is zero.

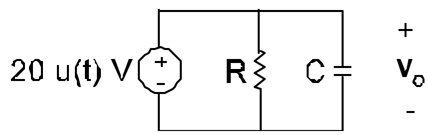


Figure P8.14

9. The presence of lead resistance in bridge-based RTD temperature measurements can lead to systemic error. Given a DIN standard platinum 100 Ω RTD, the linear approximation can be used for temperatures near 0 °C. Here, we assume 100 °C is “near” 0 °C.

$$R_{RTD} = 100\ (1 + 0.00385\ T)\ \Omega\text{, where T is in °C.}$$

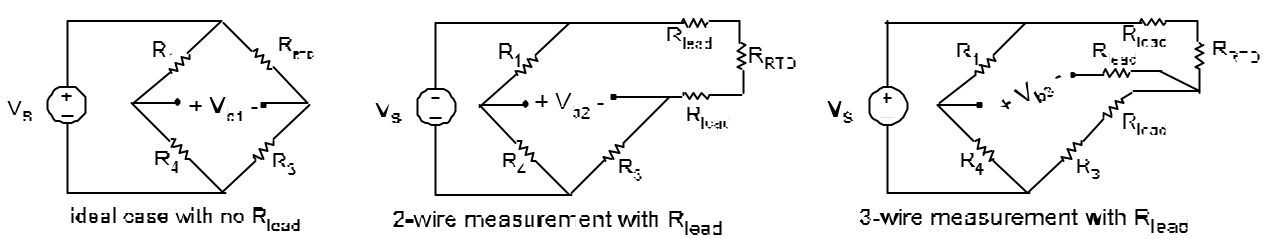


Figure P8.15

Assume $R_{lead} = 2\ \Omega$ and $R_1 = R_2 = R_3 = 100\ \Omega$.

i) Find V_{b1}, V_{b2}, and V_{b3} at 0 °C.
ii) Find V_{b1}, V_{b2}, and V_{b3} at 100 °C.

10. Improper referencing can lead to systemic error in temperature measurements using thermocouples. Assuming that type K thermocouples are being used to measure temperature, estimate the actual temperature measured and the systemic error introduced at that temperature when the reference junction is at

i) 2 °C
ii) 100 °C
iii) 250 °C

Note: The error introduced will be a voltage. Use the thermocouple tables for the type K TC to determine what the corresponding temperature error is in °C.

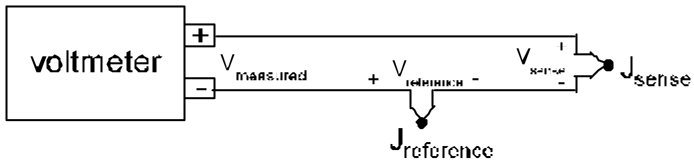


Figure P8.16